TRANSFORMING LEARNING IN WAFER FABRICATION PROCESS THROUGH SMART LEARNING SPACES

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Abstract

Training a skilled workforce for the semiconductor industry presents significant challenges due to the need for specialized equipment, complex wafer fabrication processes, and cleanroom environment. To address these challenges, Singapore Polytechnic's School of Electrical and Electronic Engineering (SEEE) has transformed the Wafer Fabrication Fundamentals (WFF) module through the integration of Smart Learning Spaces (SLS).

SLS provides a technology rich environment that enables immersive and interactive learning experiences. The tutorial lessons have been redesigned using the TPACK (Technological Pedagogical Content Knowledge) framework to integrate technology tools with teaching methods and subject expertise. Traditional lessons have been transformed into collaborative problem solving sessions where students use smart TVs to discuss and present their ideas, encouraging peer learning and knowledge sharing.

Implementing SLS requires a change in teaching method, with teaching staff playing a key role in facilitating student learning. Training sessions were conducted to equip teaching members with the skills needed to foster collaborative learning within the SLS environment. Blended learning techniques were introduced, allowing students to extend their learning beyond the classroom by observing real time wafer fabrication processes remotely. Advanced audio visual technology, including high resolution cameras and wireless audio systems, enables seamless communication among facilitators and learners, while interactive whiteboards support dynamic learning experiences.

Over a one and a half year implementation period (from 2023 Semester 2 to 2024 Semester 2), approximately one hundred and twenty second year students from the Diploma in Electrical and Electronic Engineering (DEEE) participated in SLS classroom for each semester. Students worked in teams, engaging in depth discussions and shared learning experiences, replicating real world collaborative settings. Peer learning, collaborative problem solving, and instant feedback helped students monitor their progress and enhance their understanding.

A mixed method approach, including focus group discussions and surveys, showed that SLS positively impacts engagement, understanding, and skills development. Students agreed that the learning experience in the SLS was engaging, allowed them to learn collaboratively with group mates, and provided opportunities to share their learning. This led to better knowledge retention, improved learning outcomes, and addressed the foundational training needs for a skilled workforce in the semiconductor industry. The implementation of SLS for the WFF module demonstrates how leveraging on technology and redesigning lessons can effectively motivate and facilitate student learning, with students showing improved understanding of wafer fabrication concepts, stronger peer learning capabilities, and better preparation for industry challenges.

Keywords: *Smart Learning Space, Collaborative, Peer learning, Semiconductor Industry, Wafer Fabrication*

Introduction

The semiconductor industry plays a vital role in powering today's digital world, with rapid growth demanding a workforce that can adapt and readily apply its knowledge. However, preparing such a workforce remains a significant challenge due to the complexity of wafer fabrication and the limitations of traditional teaching methods. Recognizing this gap, Singapore launched a new programme to train its semiconductor talent pool (Subhani, 2024), addressing the need for more industry ready professionals. This initiative is further supported by the government's allocation of S$1 billion for biotech and semiconductor R&D in Budget 2025, highlighting the strategic importance of nurturing skilled talent to sustain the sector's growth (Oh & Yuan, 2025).

In the School of Electrical and Electronic Engineering (SEEE), these challenges are observed in the Wafer Fabrication Fundamentals (WFF) module, a second year course within the Diploma in Electrical and Electronics Engineering (DEEE), where the delivery of hands-on training is constrained by the need for specialized equipment, complex wafer fabrication processes and the requirement for a cleanroom environment. To enhance learning outcomes, SEEE has adopted technology enabled environments that promote active, collaborative, and blended learning. These Smart Learning Spaces (SLS) integrate digital tools such as learning analytics, seamless access systems, and intelligent technologies to support adaptive and personalized learning. Research by Hwang (2014) emphasized the value of mobile and context-aware learning in enhancing personalization and student motivation, while Koper (2014) outlined the conditions for effective smart learning ecosystems that bridge formal and informal learning through data-driven personalization. Recent research by Koukaras et al. (2025) further emphasizes the transformative role of AI-driven telecommunications in enabling secure, real-time, and personalized educational experiences through smart classroom infrastructure.

The pedagogical foundation for implementing SLS is guided by the Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (2006). TPACK integrates technology with pedagogy and content knowledge to create meaningful and contextually relevant learning experiences. Chai et al. (2013) demonstrated its effectiveness in engineering education, particularly in supporting conceptual understanding through digital simulations. Niess (2005) extended the framework to mathematics education, arguing that technology must be deeply embedded within both content and pedagogy. Chai et al. (2010) proposed a developmental pathway for pre-service teachers, emphasizing the need for structured professional development.

Blended learning approaches, which combine traditional face-to-face instruction with online activities, complement the use of SLS. Garrison and Vaughan (2008) advocated for blended learning as a flexible model that supports autonomous learning, while Means et al. (2013) provided empirical evidence that it enhances theoretical understanding through multimedia simulations and remote laboratory experiences.

Collaborative learning strategies are also important to SLS. Prince (2004) reviewed the effectiveness of active learning in promoting cognitive engagement and skill development, and Johnson and Johnson (2009) emphasized the role of cooperative learning in fostering communication, teamwork, and critical thinking where these are skills essential in the semiconductor industry.

The transformation of the WFF module at SEEE exemplifies how these theoretical foundations and pedagogical strategies can be applied to support workforce development in a high tech field. Implemented across three semesters with approximately one hundred and twenty second year students, the collaborative model involved peer learning, and group presentations using digital platforms that mirror real-world industry practices. Preliminary findings from student feedback indicate increased engagement, enjoyment of collaborative experiences, and improved learning outcomes. These results align with broader educational trends, highlighting the positive impact of active and technology-based learning (Laurillard, 2012).

Purpose of Study

This study assesses the impact of Smart Learning Spaces (SLS) on learning effectiveness in wafer fabrication training through a collaborative and blended learning approach. It examines how a technology-enhanced environment bridges the misalignment between classroom learning and practical experience by integrating immersive technologies with active learning strategies. The study also includes a pilot implementation of blended learning conducted for a mass tutorial lesson which aims to evaluate how the integration of online and in-person instruction, facilitated by appropriate educational technology tools, enhances student engagement and comprehension of wafer fabrication concepts.

Research Questions

- To what extent does the SLS, enhanced with educational technology tools, support students' active participation and deep understanding of wafer fabrication concepts?
- How can educational technology tools be designed to foster meaningful peer learning and knowledge sharing during wafer fabrication training across both physical and virtual learning environments?

Materials and Methods or Pedagogy

This study adopted a mixed-methods approach to investigate the impact of Smart Learning Spaces (SLS) on the teaching and learning of wafer fabrication processes. By integrating both quantitative and qualitative techniques, the study ensured a comprehensive understanding of student engagement, instructional effectiveness, and technology integration.

Research Design and Participants

Quantitative data were collected over three consecutive semesters from second year students enrolled in the Wafer Fabrication Fundamentals (WFF) module within the Diploma in Electrical and Electronics Engineering (DEEE). The average participation rate was 73%, enabling consistent monitoring of the SLS implementation and its impact. Additionally, two focus group studies were conducted to gather qualitative insights. The first focused on evaluating the effectiveness of SLS in tutorials environments, while the second explored students' experiences with blended learning, including perceived challenges and suggestions for improvement. Each focus group comprised three to four students per class, selected to ensure diverse representation across different lecturers.

Data Collection and Analysis

Data were gathered through structured surveys using a five-point scale and semi-structured focus group discussions. Surveys assessed students' perceptions of learning effectiveness, engagement, and the integration of educational technology. Each focus group lasted about 90 minutes, was recorded, and then written out for review. A thematic analysis was applied to the qualitative data, with one group focusing on tutorial delivery and the other on blended learning experiences. Quantitative survey results were summarized using bar charts and percentages to complement and triangulate the qualitative findings.

Implementation of Smart Learning Spaces (SLS)

Phase 1: Foundations of SLS Implementation

The first phase of SLS implementation focused on preparing teaching members and fostering collaborative learning. Rather than applying the full Technological Pedagogical Content Knowledge (TPACK) framework, this stage emphasized basic digital readiness and iterative instructional design. Teaching members received basic training on SLS tools before the semester began, including demonstrations of platform features and strategies for facilitating interactive learning. Two meetings per semester were held to share feedback, best practices, and areas for improvement, supporting iterative refinement of teaching methods.

Student activities were designed to promote peer interaction and shared exploration of course content. Structured materials supported content delivery, while group tasks and discussions encouraged engagement. Technology was introduced gradually through collaborative tools embedded in the SLS platform. This phase established a foundation for more integrated and technology-enhanced instruction in subsequent stages.

Phase 2: Real-Time Blended Learning in Semiconductor Education

The second phase introduced a pilot session to explore blended learning through the integration of real-time demonstrations and theoretical instruction. The aim was to enhance student engagement and improve understanding of semiconductor fabrication processes using synchronous, multi-location learning.

The session focused on the vacuum process in wafer fabrication. One class attended the session in person at the SLS classroom, while seven other classes joined remotely from two lecture halls in Singapore Polytechnic. Two laptops were used in the cleanroom, one capturing the technical executive and the other focused on the sputtering vacuum system. To maintain clarity, only one camera feed was displayed at a time. Microsoft Teams facilitated real time interaction, allowing students to observe the process and ask questions directly to both the facilitator and technical executive.

Students received structured content before the session to support contextual understanding. During the real-time demonstration, guided questioning and peer discussions encouraged active participation. Digital tools such as screen sharing, and video streaming supported seamless delivery and collaborative learning.

While the pilot was limited to a single session, it demonstrated the potential of SLS to support engaging and effective instruction across diverse learning environments. The experience also revealed areas for improvement, particularly in the integration of technology to streamline real-time demonstrations and enhance interaction across remote settings. These insights will guide future refinements and support the broader adoption of blended learning strategies.

Results and Discussion

Phase 1: Foundations of SLS Implementation

To evaluate the initial implementation of SLS, a student focus group was conducted in fifth week of Semester 2, 2023 with 17 students across different classes. Feedback was organized into three key themes: learning environment, interaction format, and technology use.

- *Learning Environment*
  Students commended the classroom's layout for supporting visibility and collaboration. One student remarked, *"This is the best tutorial room I've ever been to."* The space encouraged participation and reduced fear of making mistakes.
- *Interaction Format*
  Tutorials involved group discussion and presentations. Students appreciated the recap sessions and felt more engaged than in traditional classrooms. However, the one-hour duration was insufficient for meaningful discussion and sharing.
- *Technology Use*
  Smart TVs were underutilized due to unfamiliarity and limited collaborative features. Students preferred verbal discussions. They also recommended more video content and thought provoking questions to deepen engagement.

Following the focus group, teaching members met during the term break to redesign tutorials, focusing on enhancing engagement through interactive content and critical thinking activities to deepen engagement. These instructional changes were later evaluated through end-of-semester surveys to support continuous improvement of the SLS experience. A cohort wide survey was also conducted at the end of the semester to gather broader feedback on SLS. Responses remained positive across three semesters, with consistently high levels of agreement despite a slight dip in top ratings. This variation may be attributed to the survey overlapping with other ongoing feedback activities.

Student Engagement Analysis

Figure 1 shows strong student engagement across three semesters. Around 90% of students agreed or strongly agreed with engagement related statements. While "strongly agree" responses dipped slightly, "agree" responses rose, showing steady positive feedback. The chart highlights SLS's role in supporting meaningful learning.

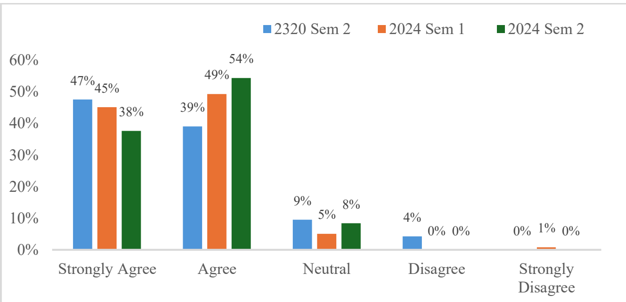

Figure 1: Student responses to the statement- I found the learning experience in the SLS to be engaging.

Student Perceptions of Group Collaboration

Figure 2 shows consistently high student satisfaction with group collaboration in SLS across three semesters. Agreement levels remained strong, with 88% to 97% of students either agreeing or strongly agreeing that SLS enhanced their collaboration skills. "Strongly agree" responses ranged from 41% to 48%, while “agree” responses stayed between 40% and 50%. These findings underscore SLS’s effectiveness in promoting peer interaction and teamwork.

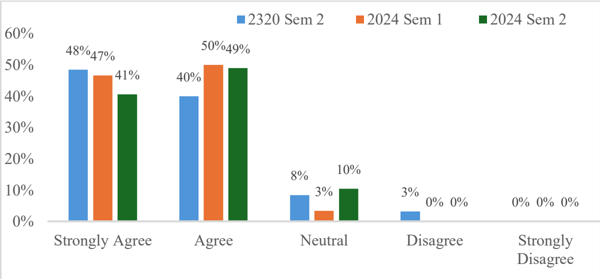

Figure 2: Student responses to the statement - I can learn collaboratively with my groupmates in the SLS

Analysis of Student Presentation Opportunities

Figure 3 shows a clear upward trend in student satisfaction with opportunities to present and share their learning. Satisfaction rose from 77% in 2023 Semester 2 to 96% in 2024 Semester 1, before dipping slightly to 89% in 2024 Semester 2, which may be attributed to a lower participation rate during or teaching staff being unfamiliar with the new setting. The increase aligns with the redesign of tutorial sessions, which likely contributed to greater engagement. These findings suggest that the revised structure effectively enhanced student participation and presentation opportunities.

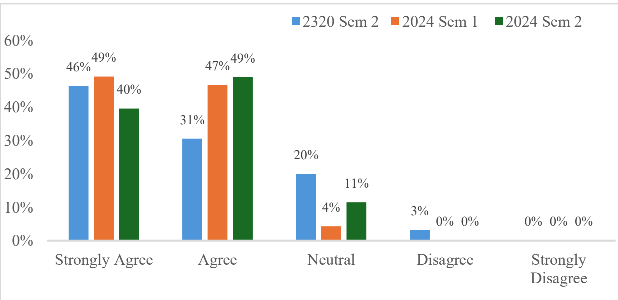

Figure 3: Student responses to the statement - I have opportunities to share or present my learning to my classmates

SLS Technology Use for Semester 2410 and 2420

As mentioned earlier, following the focus group, teaching members met to redesign tutorials with a focus on interactive content and critical thinking to deepen engagement. By the end of 2024 Semester 1, students were consistently using technological tools in the SLS. The smart TV interactive whiteboard was the most utilized feature (81% and 80%), highlighting its role in promoting engagement. PowerPoint remained the primary delivery tool. Other tools, such as internet access and document editing platforms, saw moderate but steady use, reflecting students’ willingness to engage with digital resources that support direct instruction. Figure 4 shows the comparative usage across both semesters.

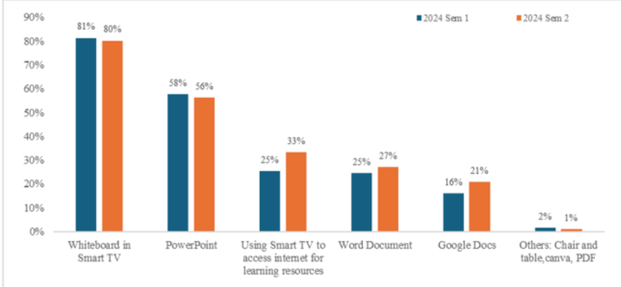

Figure 4: Student responses to the statement - Which of the following have you used in the SLS?

Phase 2: Real-Time Blended Learning in Semiconductor Education

A blended learning approach was implemented for teaching vacuum technology in wafer fabrication, designed to enhance student engagement and bridge theoretical concepts with practical applications. The session involved seven classes across two lecture halls, with an additional class connected through the SLS. The learning experience was coordinated between a facilitator in the SLS environment and a technical executive conducting real-time demonstration the cleanroom, while facilitators in lecture halls connected via Microsoft Teams to ensure synchronous participation.

This integrated approach combined digital and physical learning environments, enabling students to observe and understand practical applications through real-time demonstration. Post-session surveys assessed three aspects: blended learning effectiveness, theory-to-practice application, and lesson engagement. Feedback from this setup is shared in the following section.

Student Feedback on Blended Learning Effectiveness

Feedback gathered from different learning settings revealed distinct patterns in student experience. Students connected through the SLS responded positively, with 74% indicating the lesson was effective and no negative responses recorded. This suggests that the real-time facilitation and interactive features of the digital environment contributed to stronger engagement and clearer understanding.

In comparison, feedback from students in lecture halls was more mixed: 38% found the session effective, 25% were neutral, and 37% disagreed.This contrast may highlight the limitations of conventional setups, which typically rely on basic tools like projectors, speakers, and wired microphones. Figure 5 compares student feedback, showing stronger outcomes in SLS-enabled classrooms and highlighting the need for better tech in lecture halls.

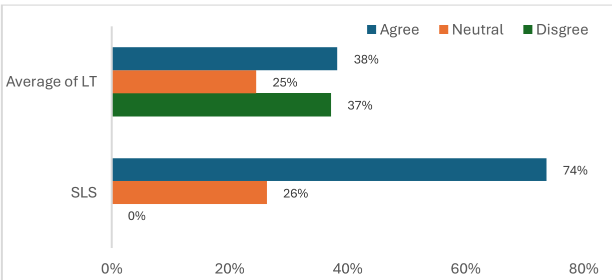

Figure 5: Student responses to the statement - The lesson was effective in helping me understand vacuum processes in wafer fabrication

Student Feedback on Application of Theory to Practice

Students engaged in a blended learning session featuring a real-time vacuum process demonstration through Microsoft Teams. The session, hosted in the SLS environment, was facilitated by a technical executive using two laptops. One laptop captured the technical executive providing the instructional teaching. The other displayed the vacuum system of the sputtering process with a single pinned camera view to maintain clarity.

Student feedback indicated that 74% of those in the SLS environment felt the session enhanced their understanding of both theoretical and practical aspects, compared to 43% of students in traditional lecture halls. Only 5% of SLS participants expressed disagreement, whereas 35% of students in the traditional lecture hall setting did not find the session beneficial. Figure 6 illustrates this contrast in perceived learning effectiveness across the two environments.

These findings suggest that the interactive, guided approach within the SLS environment enhanced student engagement and comprehension. To further optimise the experience in SLS, improvements in camera angles and audio quality during real-time session in the cleanroom could be considered. Meanwhile, the varied responses from lecture hall students point to a need for greater interactivity and instructional support in traditional settings.

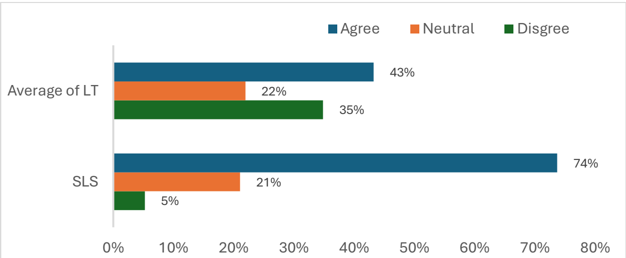

Figure 6: Student responses to the statement - The lesson enhanced my understanding of how theoretical concepts apply to practical vacuum processes.

Student Feedback on Lesson Engagement

As shown in Figure 7, 74% of students in the SLS environment found the lesson engaging, with only 5% expressing disagreement. In contrast, just 35% of students in traditional lecture halls agreed, while 39% disagreed and 27% remained neutral. These findings suggest that the structured and interactive nature of the SLS environment significantly enhanced student engagement. The contrast underscores the need for traditional settings to adopt more interactive strategies and technologies to improve participation and attention.

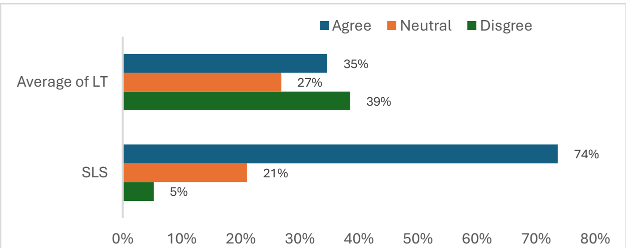

Figure 7: Student response - I find the lesson engaging.

Focus Group Study: Lecture Hall Experience

Student feedback on lesson effectiveness, theory-to-practice application, and engagement revealed clear contrasts between learning environments. Students in the Smart Learning Space (SLS) reported higher satisfaction, with 74% finding the sessions both effective and engaging. In contrast, students in traditional lecture halls expressed lower satisfaction, pointing to limitations in supporting blended learning.

To gain deeper insights into the challenges of traditional settings, a focus group was conducted with lecture hall participants. The discussion revealed a mix of positive observations and constructive suggestions, summarized into five key themes:

- *Demonstration and Practical Understanding*
  Students appreciated the real-time demonstration, especially the ability to zoom in on specific components of the vacuum system, which one stated "really helped us understand how it works."
- *Peer Learning Experience*
  Learning alongside friends was seen as beneficial, with students noting it was "easier to learn when you're with friends" as it encouraged informal discussion and comfort in asking questions.
- *Instructional Delivery*
  The session was overly reliant on slides and lacking interaction, with one student describing it as "just another lecture" with limited engagement.
- *Technology and Infrastructure*
  Technical issues such as poor audio, unstable internet, and slow screen transitions were common, and one participant shared that "the screen froze or the audio cut out," making it difficult to stay focused.
- *Suggestions for Improvement*
  Students recommended smaller group formats to improve interaction and suggested allowing online learners to join from anywhere, saying it would "make it easier to ask questions and stay engaged."

A key recommendation was to conduct future blended sessions in smaller groups to improve interaction and engagement. Students also suggested allowing online learners to join synchronously from any location. Overall, the findings highlight the need to strengthen both technology and teaching approaches in traditional lecture settings to support more effective blended learning.

Conclusion

This study investigated how Smart Learning Spaces (SLS), supported by educational technology, can enhance student participation and understanding in wafer fabrication training. In Phase 1, the Wafer Fabrication Fundamentals module was redesigned to move away from passive lectures and toward more active learning. Students responded positively, reporting higher engagement and greater confidence in sharing ideas. Tools that encouraged inclusive participation and peer teaching played a key role in this improvement.

Phase 2 built on this by introducing a blended learning model that combined real-time demonstrations with digital delivery through the SLS. Students in the

SLS environment reported higher satisfaction with lesson effectiveness, engagement, and the connection between theory and practice, compared to those in traditional lecture halls. These results suggest that the use of interactive tools and structured digital environments can significantly improve learning outcomes.

However, engagement in Phase 2 was slightly lower than in Phase 1, likely due to the challenges of managing both in-person and remote learners simultaneously. Feedback from focus groups from students in the lecture halls pointed to the need for smaller group formats, better audio-visual systems, and more interactive teaching strategies to maintain attention and support knowledge sharing across different settings.

As shown in recent studies, smart learning environments that integrate digital tools, real-time feedback, and flexible delivery methods support students' active participation and promote deeper understanding. This study supports those findings, showing that a well-designed SLS can bridge the gap between theory and practice, and foster collaboration in both physical and virtual classrooms.

Going forward, future research could explore the long-term impact of SLS on student performance and workforce readiness. There is also potential to enhance learning through industry partnerships and emerging technologies such as AI-driven feedback and engagement tracking, which can help tailor instruction to individual needs and improve overall learning experiences.

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